



*... for a brighter future*

# ***Metamaterial-Loaded Waveguides and Dark Current and Breakdown Studies (proposal)***

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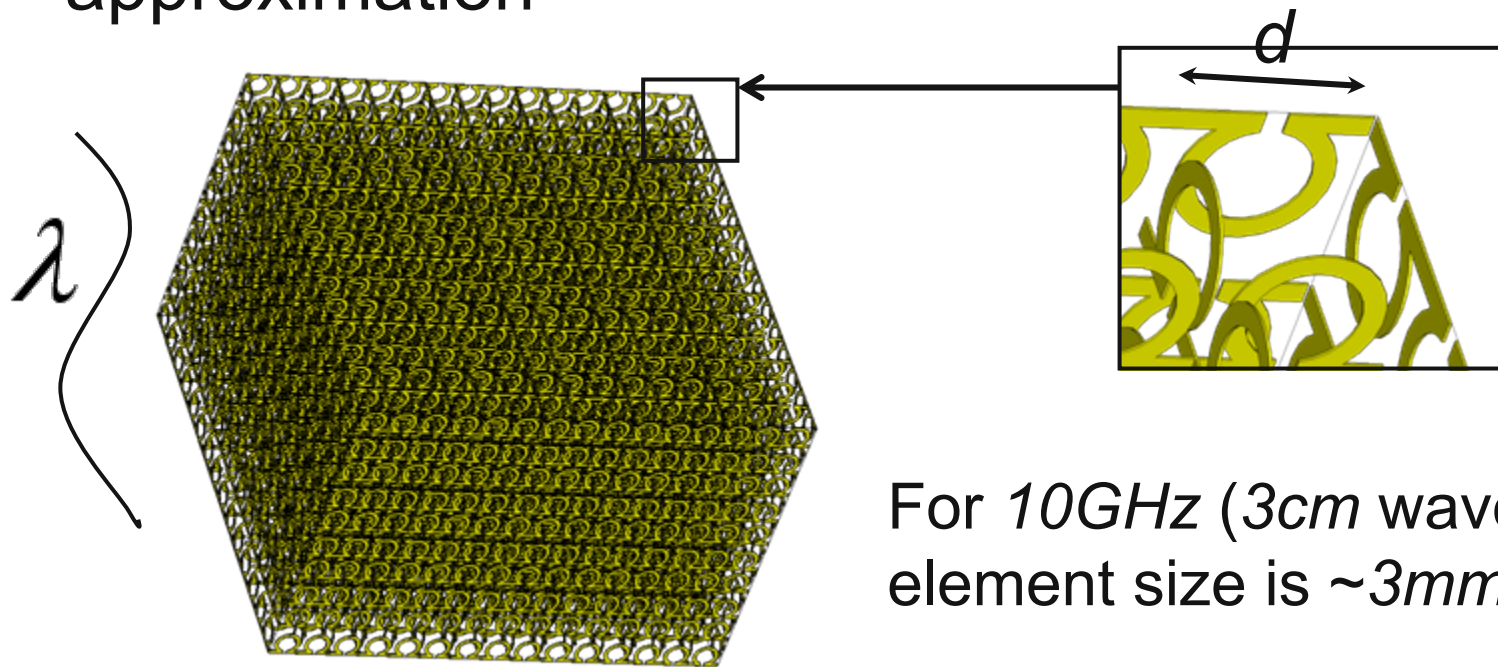
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## Introduction

- Metamaterials (MTM) are manmade materials with desired (electromagnetic) properties.
- For simplicity of design and manufacturing they are **arrays of cells** or basic elements

Effective media approximation

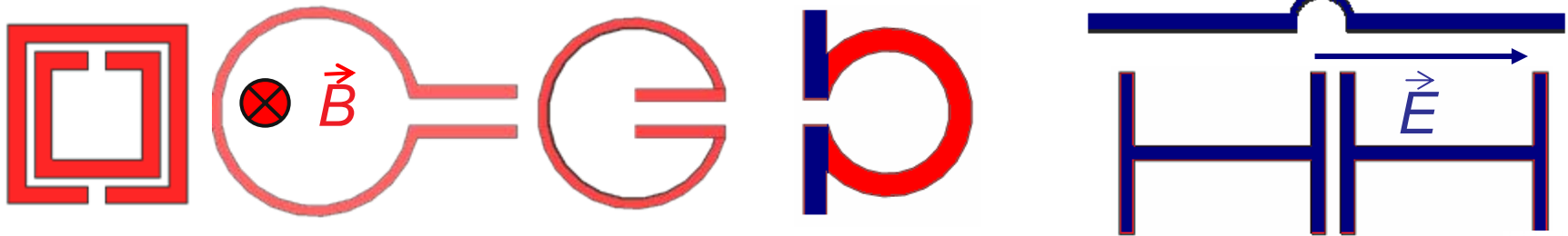
$$\lambda \gg d \Rightarrow \exists \hat{\epsilon}(\omega) \text{ and } \hat{\mu}(\omega)$$



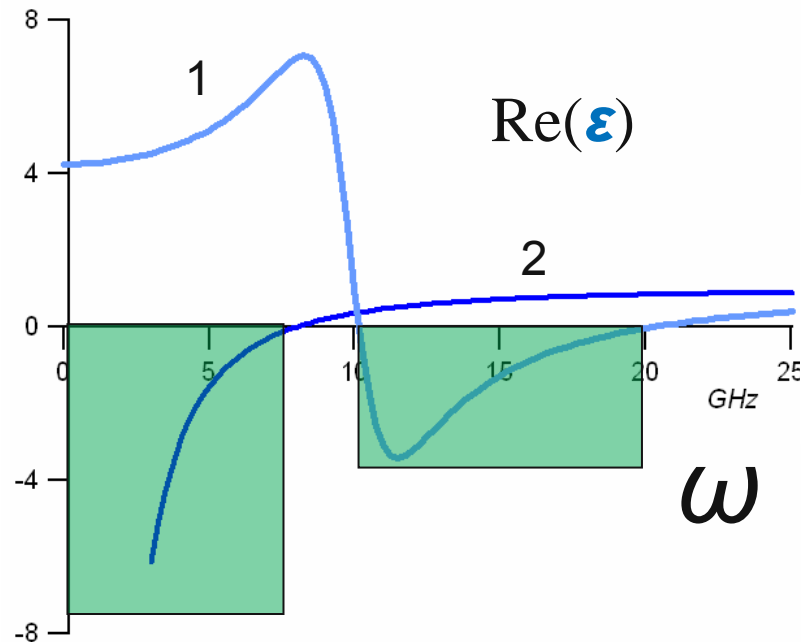
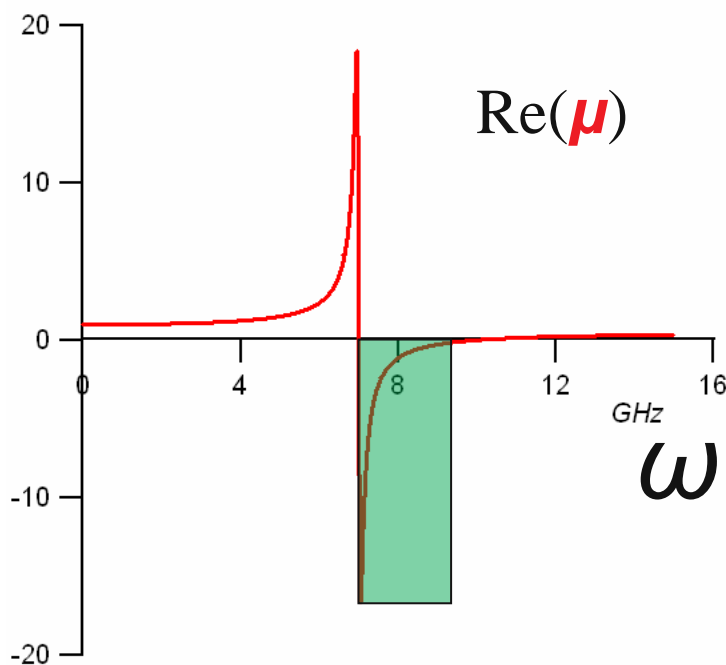
For 10GHz (3cm wavelength)  
element size is  $\sim 3mm$

# Metamaterial elements

- Different geometries were studied (note anisotropy).



- For certain polarizations of fields they produce different responses:



- We combine different elements to produce metamaterials with simultaneous  $\epsilon < 0$  and  $\mu < 0$ .

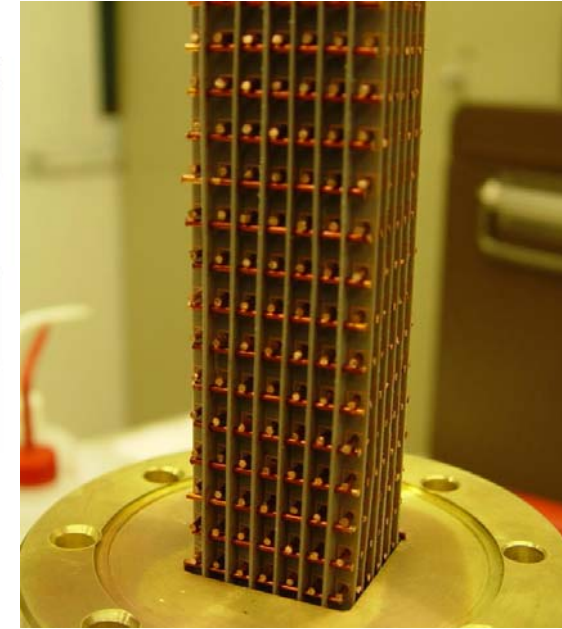
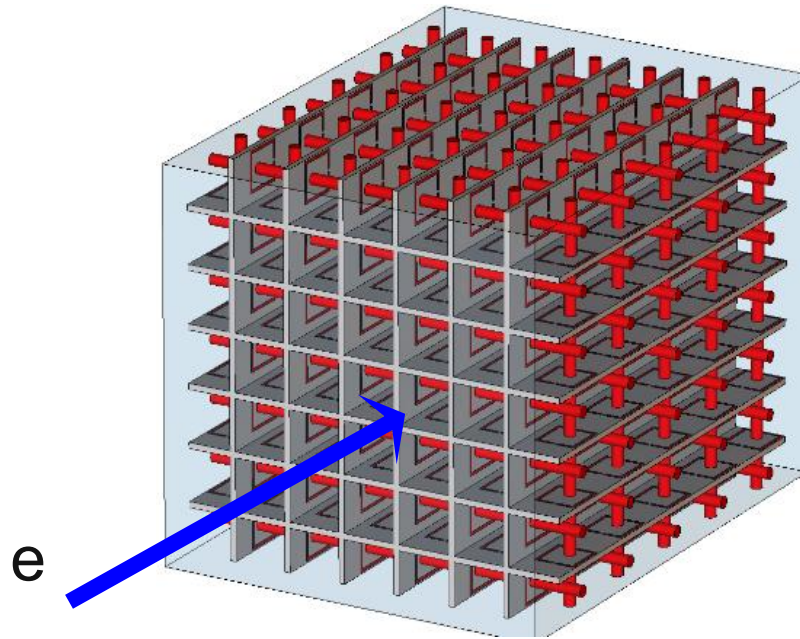
# TM Modes in MTM Loaded Waveguide (z-oriented)

$$\hat{\epsilon} = \begin{pmatrix} \epsilon_{\perp} & 0 & 0 \\ 0 & \epsilon_{\perp} & 0 \\ 0 & 0 & \epsilon_{\parallel} \end{pmatrix}$$

$$\epsilon_{\perp}(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + i\gamma\omega}$$

$$\hat{\mu} = \begin{pmatrix} \mu_{\perp} & 0 & 0 \\ 0 & \mu_{\perp} & 0 \\ 0 & 0 & \mu_{\parallel} \end{pmatrix}$$

$$\mu_{\perp}(\omega) = 1 - \frac{\omega^2}{\omega^2 - \omega_0^2 + i\gamma\omega}$$

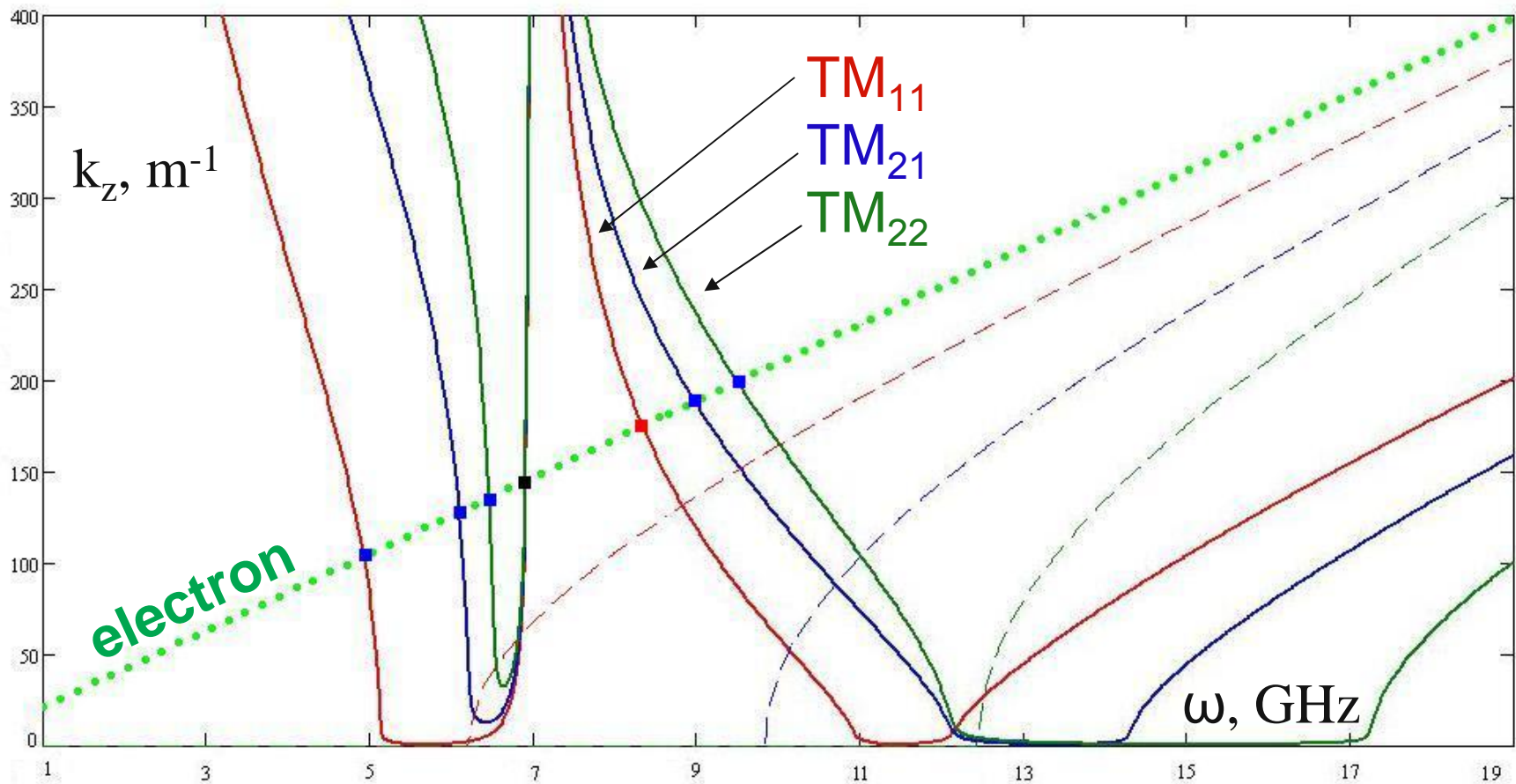


Metamaterial designed and fabricated at AWA

Dispersion for TM modes in rectangular waveguide:

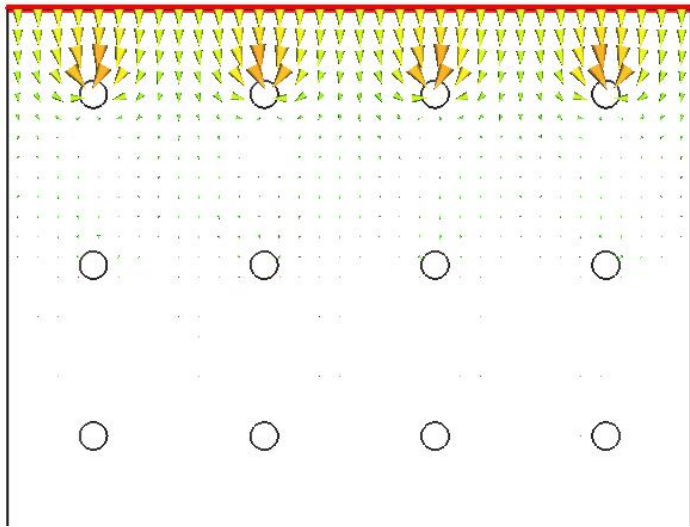
$$k_z = k_0 \sqrt{\epsilon_{\perp} \mu_{\perp} \left( 1 - \frac{\chi_x^2 + \chi_y^2}{\epsilon_{\parallel} \mu_{\perp} k_0^2} \right)}$$

## Mode excitation analysis



- Provides frequency of generation for each mode
- Does not provide energy exchange (beam dependent)

## Application: accelerator with dipole mode suppression

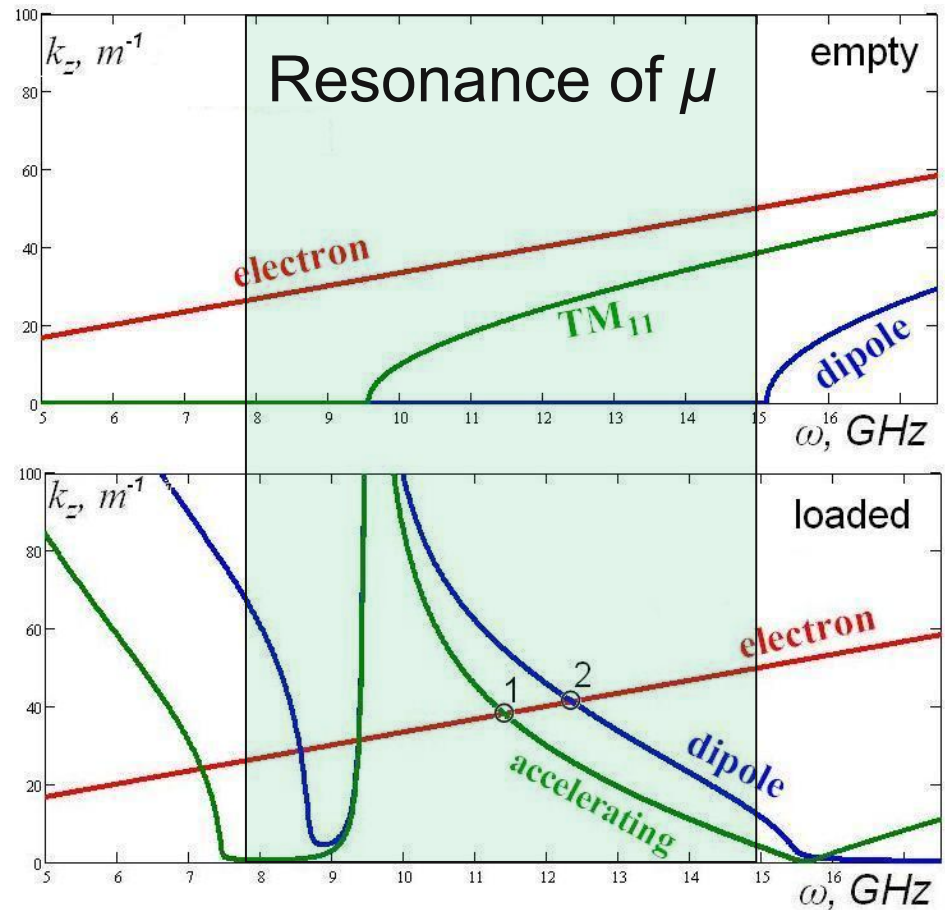


Non-magnetic regime does not exist for wire array!

This is an idea:



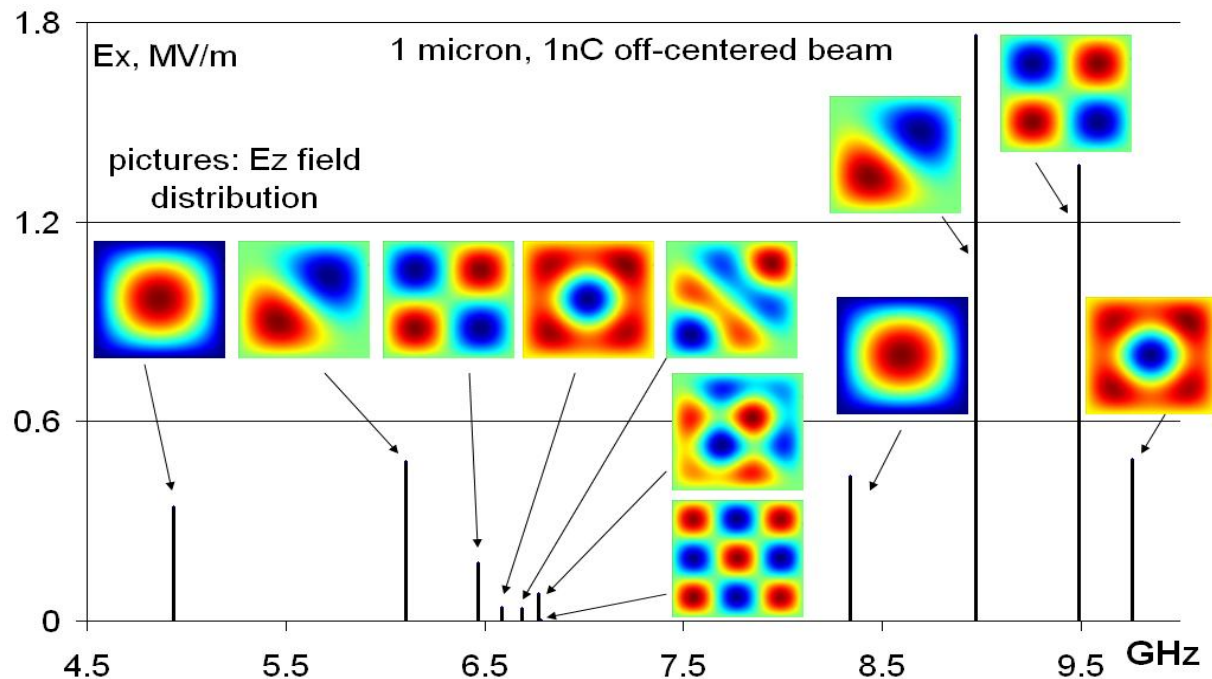
We do not discuss losses,  
mode coupling,  
breakdown, charging etc..



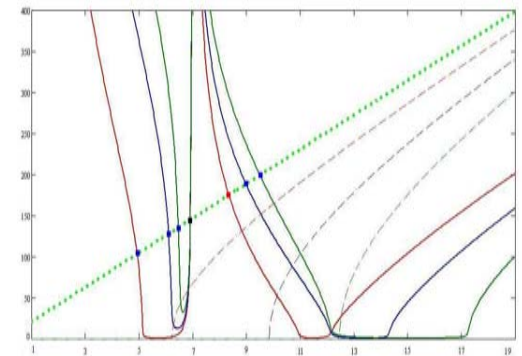
High order modes synchronize in non-magnetic region

# Wakefield simulation in metamaterial-loaded waveguides

- Long waveguide of any cross section
- Uniformly ( $\perp$ ) loaded with anisotropic and dispersive media
- “Pancake” beam ( $\delta(z-vt)$ ) passing along waveguide axis
- Fourier transform in time and  $z \rightarrow$  2D simulation with parameter  $\omega$
- Postprocessing: FFT for simple cases or spectrum calculation through residues
- Successfully benchmarked for dielectric loaded waveguide against A. Kanareykin et al script, and W. Gai, J. Power script

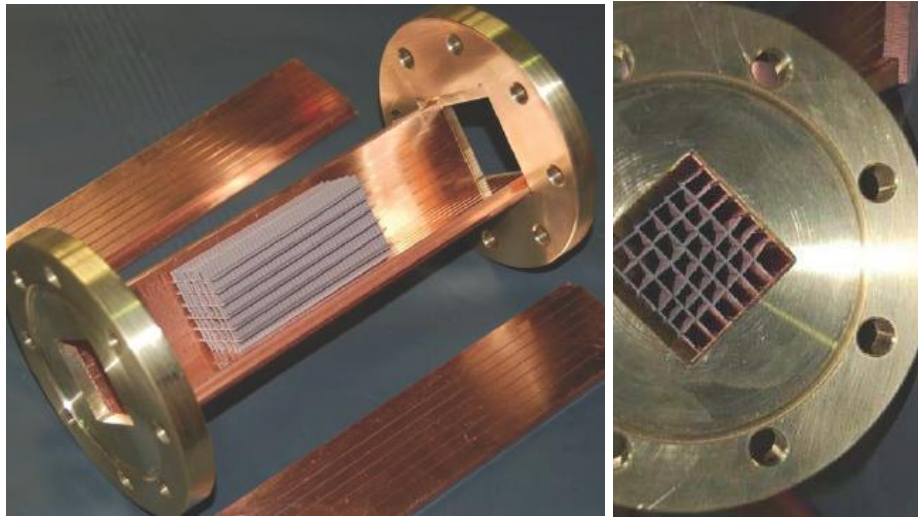
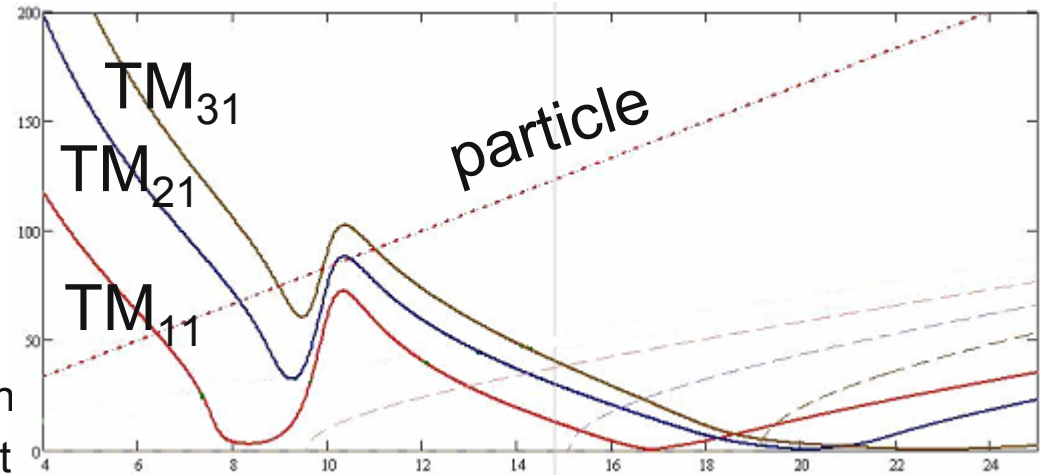


Off-center, micron-size beam is resolved in FEM



## Particle – metamaterial interaction: distinctive features

- Backward modes
- Several excitation regimes
- Multithreshold excitation (non-magnetic – left-handed regime)
- Strong dependence on longitudinal distribution (future studies)
- Stronger signals at resonance
- High angle values for Cherenkov Radiation cone in bulk configuration
- Backward radiation in bulk (was not yet observed)



Future plan is the wakefield experiment on the beamline

The goal is to detect backward mode

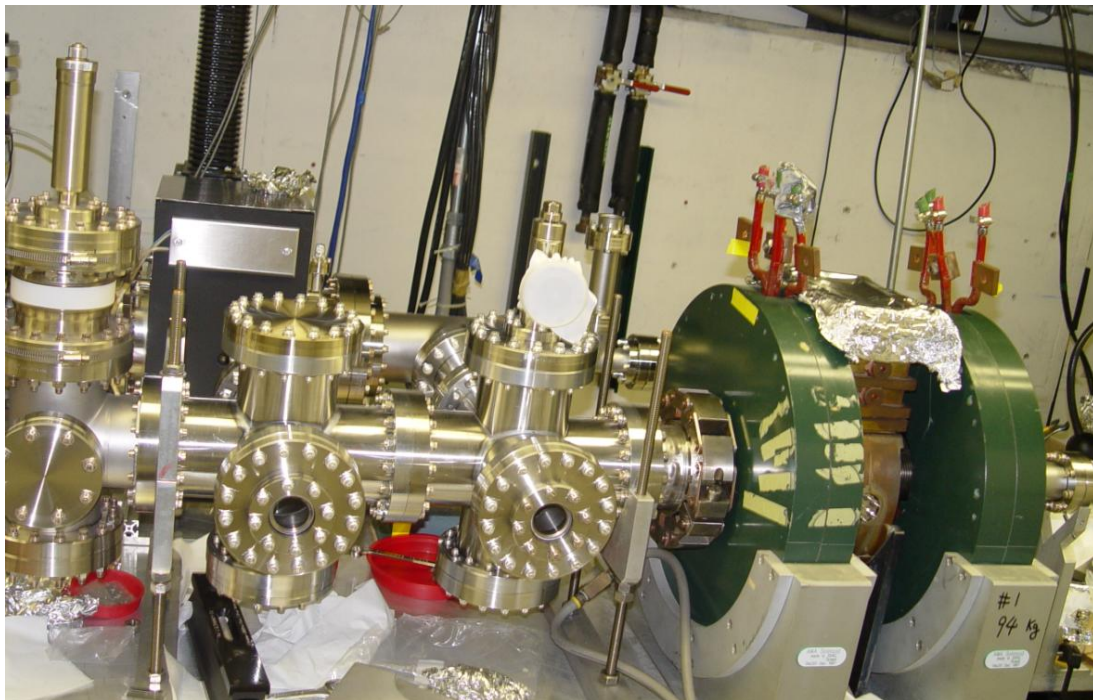
## Motivation

- Relationship between surface features and dark current is not known (geometry, impurities, bulk properties...)
- Number and distribution of emitters is not known
- Dark current is reproducible from pulse to pulse. Unless such catastrophic event as an RF breakdown happened, *images of emitters* don't move

## Proposal

- We want to use 1.3GHz gun with a removable cathode for study of *microscopic* properties of dark currents and breakdowns.
- Specific problem: understanding the dark current behavior as a function of its properties due to material it is made of and surface condition.
- Get insight into physics of rf conditioning.

## 1.3 GHz RF Photocathode Gun at the AWA



- **Removable cathode**
  - Test different materials
  - Test different surface preparation
- **Diagnostics & Tools**
  - High resolution images of YAG-screen and photocathode
  - Standard diagnostics available: energy, faraday cup, streak camera, etc.
  - Laser (248 nm, 372 nm, 744 nm) available to trigger a breakdown

# Proposed studies of microscopic properties of dark currents

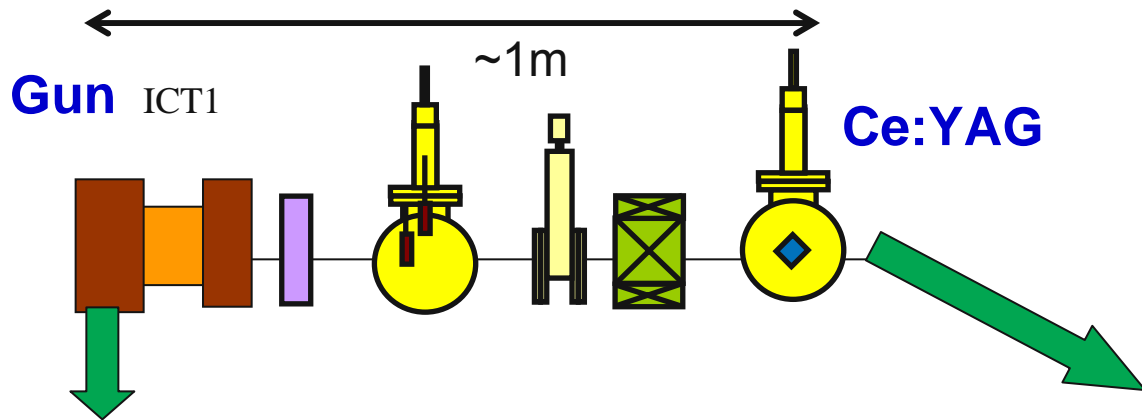
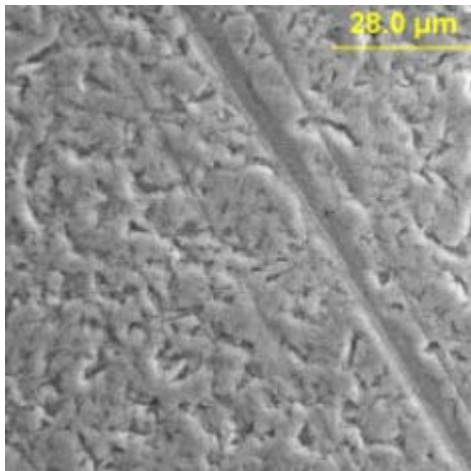
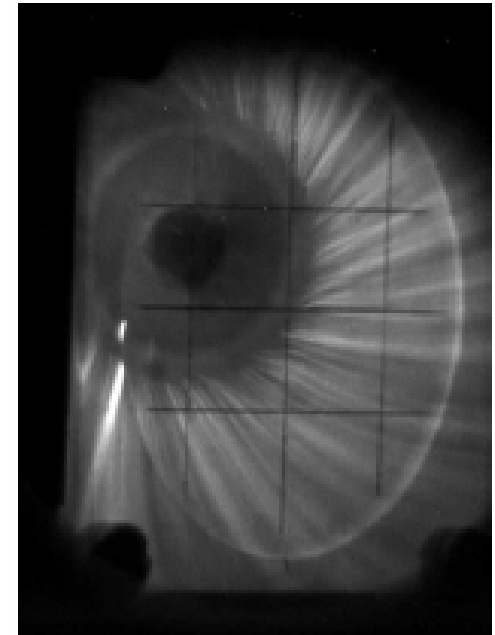


image of the dark current  
at YAG screen



Source of dark current:  
geometry, impurities,  
bulk properties ...



Surface Analysis of  
the cathode

emitter site ← streaks